ARC DISCHARGE SOURCES

Semiannual Report Covering Period from
15 April 1966 to 15 October 1966

15 November 1966

Contract Nonr 4647(00)
ARPA Order No. 306-62
Code No. 4730
Req. No. NR-012-511, January 7, 1966

A 28-Month Contract
Expiration Date February 28, 1967
Cost $195,933

Charles H. Church, Principal Investigator (412) 256-3678
B. W. Swanson R. Liebermann
P. Buchhave E. Geil
G. Basi L. A. C. Weaver

R. D. Haun, Jr., Manager
Quantum Electronics

Westinghouse Research Laboratories
PITTSBURGH, PENNSYLVANIA 15235

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Pittsburgh, Pennsylvania 15235

TABLE OF CONTENTS

LIST OF FIGURES

PREFACE

The purpose of this investigation is to develop theoretical models for the high energy pulsed arc discharge. These models, after validation by experimental measurements, are to allow prediction and optimization of the performance of pulsed arcs for high energy laser pumping.

This report presents our progress to date towards this goal. The techniques used have been as basic as possible to allow extensions to gases other than argon and xenon. Through this work, we hope also to gain a better capability to predict properties of high density plasmas such as those found in many plasma systems in addition to the pulsed high energy laser pump.

ABSTRACT

This report describes the recent work on the development of theoretical models for the pulsed xenon arcs used in high energy laser pumping. Included in this report are the results of theoretical calculations of line broadening and spectral absorptivities in xenon, and techniques for calculating the partition of energy in the flash tube between thermal and radiative conduction to the wall, and radiation external to the tube.

Experimental work in the report include measurements to describe the energy partition between conduction and radiation, and of the temperature profile of the arc. Progress toward more accurate measurements of the physical characteristics of the arc plasma are also described.

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1. INTRODUCTION

The pulsed arc discharge presently is the most efficient optical pump for high energy lasers. The purpose of this investigation is to gain a further understanding of the processes of light emission from pulsed arc discharges, and to apply this knowledge to improve the optical pumping of high energy lasers.

The approach used in this study as it has been described in the three previous semiannual reports[1,2,3] is to construct models for pulsed arcs which describe as quantitatively as possible the light emission from the discharge as a function of the flash tube parameters. These parameters include the intrinsic parameters of the flash tube: diameter, shape, and gas fillant, and the operating conditions of electric field and current.

In this phase of the study of pulsed laser pumps, we have concentrated our attention upon xenon gas fillants for the flash tube. Xenon presently gives the highest efficiency and is the gas most commonly used in pulsed flash tubes. In other work[4,5] we have been and are currently studying metallic arc plasmas, primarily for continuous and low power density pulsed laser pumping.

The choice of xenon as a subject of study gave a closer approach to application, but has led to a more difficult atomic system to study. These difficulties arise from the multielectron structure of xenon, and the resulting complexity of the theories of physical properties with which we were concerned. The techniques being developed in these studies are sufficiently general that atomic species other than xenon can be handled in later work. The degree of difficulty in further applications would depend upon particular atomic or molecular species being considered.

The work thus far may be divided into three areas:

1. The development of models for the arc in which the spatial variation of the temperature and thus the physical properties are explicitly included.

2. The development of theoretical expressions for the temperature- and pressure-dependent physical properties. The properties required thus far are the electrical and thermal conductivities, and the spectral absorptivities including those arising from the free-free, bound-free, and bound-bound processes. The latter spectral absorptivities must include the effects of pressure broadening.

3. Experimental verification of the models. In most of the work, the experimental measurements have procured new information on those physical properties of xenon.

Figure 1 illustrates in flow chart form proceeding from left to right the methodology of our studies of the arc plasmas. The figure shows calculations of the physical properties, of the solving of the models, and the experimental observations. We assume that the plasma in the flash tube is in local thermal equilibrium (LTE) which is a type of equilibrium in which Boltzmann's and Saha's equations are assumed valid and there are many more collisional than radiative events taking place per unit volume. This was discussed more thoroughly in the first report.[1]

For the purpose of these calculations, we are using semi-empirical models for atomic systems which are based upon the observed differences in the energy levels of the atom in question from that of the hydrogen atom, or the "quantum defect method" as it is commonly referred to in the literature, (Seaton[6] applies the term "quantum defect method" to a particular mode of calculation of the bound-free continuum which was originated by him).

From Moore's Tables of Atomic Energy Levels,[7] using quantum defect methods (which is a subject of or is applied in many current investigations described in the earlier semiannual and quarterly reports), the spectral absorptivities can be calculated. Theoretically, the scattering cross sections required to calculate the electrical and thermal conductivities could also be calculated in a fashion similar to the spectral absorptivities (they are directly related) but we will not discuss that here. We will discuss the various parts of Figure 1 in later sections of this report.

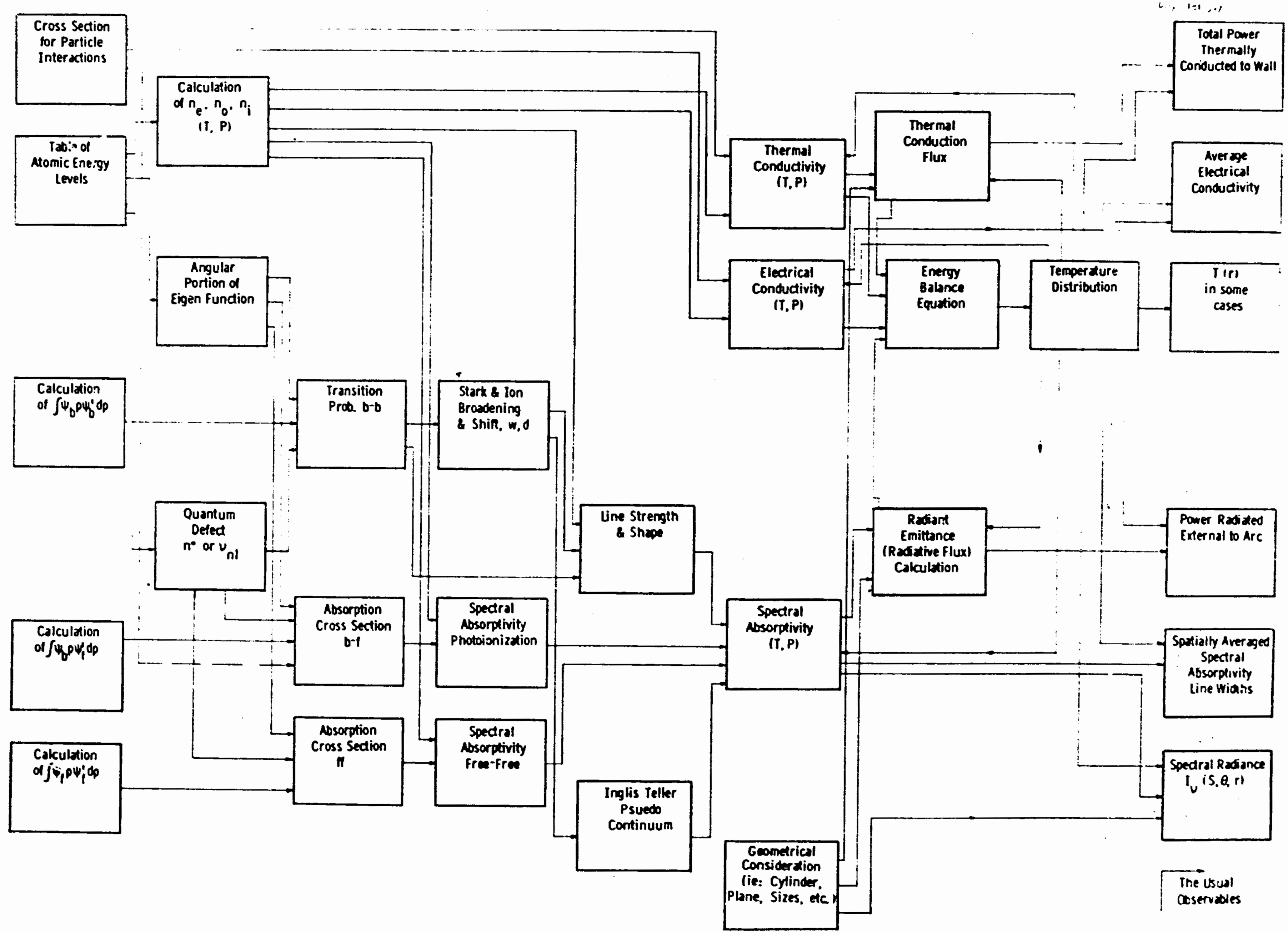

Fig. 1—Procedure for calculation of properties of arc discharges in atomic gases satisfying local thermal equilibrium using quantum defect method

The effort on the model studies has been towards the development of methods to solve the energy balance equation, which is the relation connecting the electrical power input with the radiated and thermally conducted output. We would like to obtain as high a precision as possible. We also wish to develop simple physically reasonable models which can be applied readily to laser pumping geometries more complex than that of the infinite circular cylinder.

The need for calculation of the physical properties required for the energy balance equations has led to programs for the electrical and thermal conductivities as a function of temperature and pressure. These calculations include the effects of electron-neutral, electron-ion and electron-electron interactions.[8] We have also developed procedures for the calculation of the electron broadening of the lines in argon and xenon; broadened lines are being added to the continuum absorptivities due to Schlüter described in the earlier reports.[2,3] We are also developing programs for calculating the bound-free and free-free spectral absorptivity using the methods of Schlüter[9] and of Peach[9,10,11] based primarily upon the quantum defect calculations of Seaton,[6] and Burgess and Seaton.[12]

The experimental work has been directed towards validating the calculations of the physical properties and providing checks on the various aspects of the theory including the energy balance. A set of measurements currently in progress seeks to separate the energy transferred external to the arc from that deposited at the walls. These measurements are based upon the simple phenomenological model mentioned earlier, and to be described in detail in later paragraphs. The measurements of spectral absorptivity and line shape, which are to use the recently developed spectrometers[13,14], are intended to check the Stark broadening and spectral absorptivities calculations we have made for xenon.

The final forms of the computer programs used in this work will be presented in the final report.

2. RADIATIVE ENERGY AND THE MODEL STUDIES TRANSPORT

The current model studies have taken three concurrent approaches, primarily arising from the complexity of handling energy transfer in nongray, nonhomogeneous temperature arcs. The first approach, that of Swanson described in the earlier reports[1,2,3], treats the varying absorptivity in the calculation of the radiative flux exactly[1,2] or as described in the later report[3] by more complete than usual approximation. These techniques are being applied to the solution of the energy balance equation. The problem is still the slow rate of convergence to a temperature profile.

The second technique, due to Lowke and Capriotti,[15] uses a number of averages to simplify the radiative flux integrals and to obtain a convergent solution form to the temperature profile that is the solution to the energy balance equation. This technique converges to a temperature distribution quite well. The techniques of Swanson[2,3], and of Lowke and Capriotti[15] are presently being compared part by part. It appears that a final method will be a combination of the best features of each.

The third method for handling the arc model is similar to the channel models of Maecker and others (see the first report[1]), but appears to be more reasonable when applied to a pulsed arc. In this model, the major portion of the energy transferred from the core to outside the flash is considered to be radiated from the (on the average) central homogeneous temperature core of the arc which varies in diameter with diameter of the flash tube for a linear arc tube. The energy transferred to the walls by thermal conduction and optical radiation for wavelengths for which the flash tube is opaque arise from a thin layer of gas having a high temperature gradient (i.e.: from the flash tube wall temperature to the arc core temperature). The thickness of this thermal conduction layer is considered not to vary appreciably with power input to the tube though it has been found experimentally to vary appreciably with flash tube diameter. With these assumptions, the power input to the flash tube divides into two components: a thermal conduction component which depends upon the

core temperature and the thickness of the boundary layer, and a radiative component which can be calculated for a homogeneous temperature cylinder. This simple model is being tested experimentally by measuring the spectral radiance of the arc column (and thus temperature from which we can calculate the spectral radiant emittance and the radiant emittance), as a function of power input for various tube diameters.

This simple model when verified can be used to calculate the energy partition and thus the efficiency of various geometries including the coaxial lamp[17] which are more difficult theoretically than the simple infinite circular cylinder being investigated exactly in these investigations.

3. THE PHYSICAL PROPERTIES

The physical properties that were required for this phase of the model studies, the study of a fully developed pulsed arc, were the electrical and thermal conductivities, and the spectral absorptivities. The latter included both discrete and continuum absorptivities.

Thermal and Electrical Conductivities

The theoretical calculations for the electrical and thermal conductivities were made by Dr. R.S. deVoto of Stanford University.[8] His calculated electrical conductivities have shown good agreement with values of electrical conductivity measured in the flash lamps. This work will be described in a forthcoming report. Figure 2 shows some theoretically calculated values for the electrical conductivity as a function of temperature at various pressures typical of those found in the flash tube. Figure 3 shows similar plots for the thermal conductivities at similar pressures.

The Spectral Absorptivities

The calculation of the spectral absorptivities has a number of different parts as can be seen from Figure 1. At present, we are using

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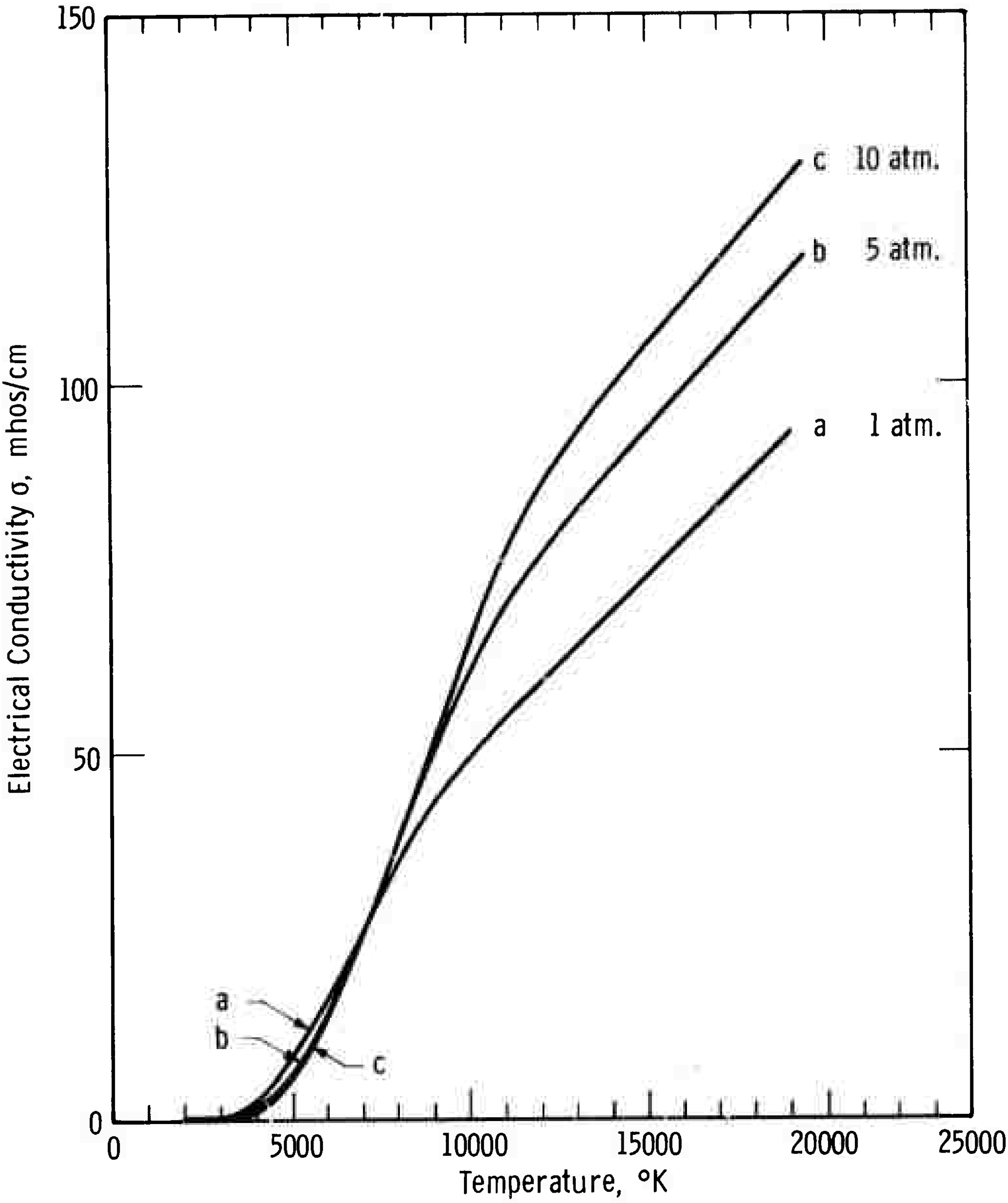

Fig. 2—Electrical conductivity of an equilibrium xenon-plasma calculated according to R. S. deVoto [8] for 1, 5, and 10 atmospheres pressure.

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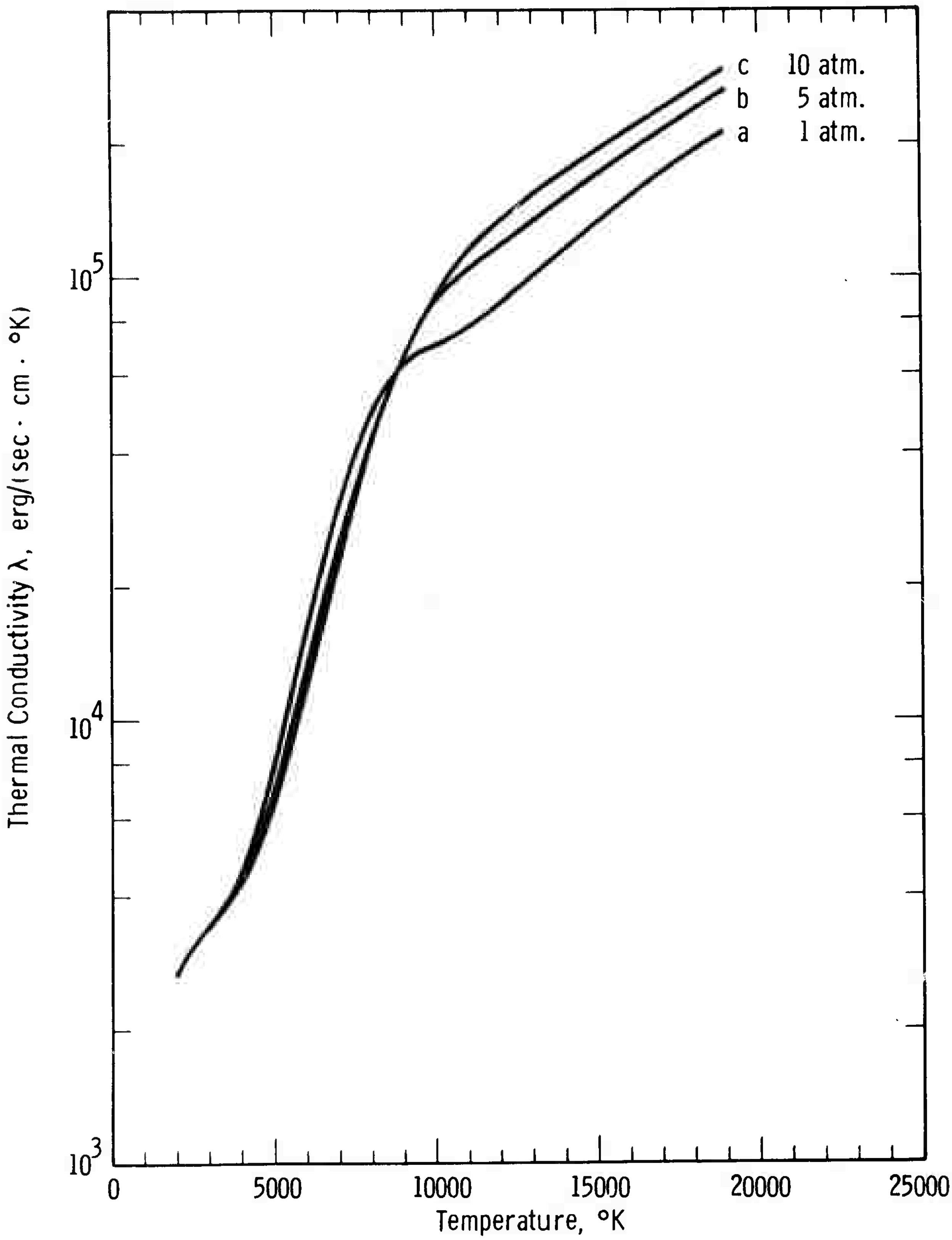

Fig. 3—Thermal conductivity of an equilibrium xenon plasma calculated according to R. S. deVoto[8] for 1, 5, and 10 atmospheres pressure

the continuum absorptivity calculations due to Schlüter.[9] He explicitly calculated the bound-free spectral absorptivity and then included the free-free and psuedo continuum by adjustment factors based upon Kramers-Unsold theory and the Inglis-Teller rules.[9] The calculated continuum showed good agreement with our measurements in the ultra-violet.[3] We in turn are adding to this continuum spectral absorptivity the contribution of the strong very broadened lines lying primarily in the near infrared. This technique at present suffers from a lack of a good criteria on which lines to include explicitly and which lines are already implicity included in the other processes. Calculations that we have in progress will allow calculation of each of these factors (bound-free, free-free, and pseduo-continuum) explicitly. These calculations require programs to integrate Whittaker's functions of real and imaginary arguments. These programs will be described in the next report.

To include the lines of xenon in the spectral absorptivities, a series of programs, based on an electron-broadening calculation by E. Corinaldesi[18], was developed for xenon. These programs considered xenon to be j-l coupled, and included in them adaptions of the Scaled-Thomas Fermi potential of Stewart and Rotenberg[19] to calculate the radial portion of the eigenfuction. These programs used as input the Table of Atomic Energy Levels[7], and the temperature and pressure to be considered. The output of the programs is a table of the allowed transitions between levels of number N and M where the numbers N and M are obtained by numbering the levels in Tables of Atomic Energy Levels from 1 (the ground state) up consecutively. The computer output shown in Figure 4 for a particular temperature and pressure includes the wave number and wavelength (vacuum) of each allowed transition, and the product fN_L where f is the absolute absorption oscillator strength, and N_l is the density of the lower level in particles per cm^3. It also shows $\Delta\nu_w$ the width, and $\Delta\nu_o$ the shift of the transition due to electron broadening (referred to 10^{18} electron/cm^3), and the spectral absorptivity at the center of the shifted line. The equation for the spectral absorptivity

TEMP= 10000.0 PRESSURE= 7.65

N	M	FXN(N)	DELTA NU CM-1	NUO CM-1	WAVELENGTH ANGSTROMS	DELTA NU D CM-1	NU(NM) CM-1	KAPPA PRIME(NUO)
1	3	4.0298e+13	2.081e+00	6.805e+04	1.470e+03	2.166e+00	6.804e+04	5.457e+05
1	17	1.2121e+19	4.516e+00	7.999e+04	1.250e+03	-8.021e-01	7.999e+04	7.563e+05
2	6	3.4577e+14	5.799e+00	1.020e+04	9.802e+03	2.022e+00	1.020e+04	1.293e+01
2	7	7.3781e+13	6.665e+00	1.105e+04	9.048e+03	3.166e+00	1.105e+04	2.483e+00
2	8	1.0501e+15	8.477e+00	1.134e+04	8.822e+03	4.553e+00	1.133e+04	2.807e+01
2	9	7.6839e+13	6.853e+00	1.189e+04	8.411e+03	3.480e+00	1.189e+04	2.588e+00
2	10	6.9663e+14	8.113e+00	1.214e+04	8.234e+03	4.158e+00	1.214e+04	1.998e+01
3	6	5.7847e+13	5.978e+00	9.224e+03	1.084e+04	1.793e+00	9.222e+03	2.004e+00
3	7	5.6402e+14	6.844e+00	1.007e+04	9.926e+03	2.938e+00	1.007e+04	1.777e+01
3	9	3.3116e+14	7.032e+00	1.091e+04	9.165e+03	3.251e+00	1.091e+04	1.051e+01
3	10	6.7018e+13	8.292e+00	1.117e+04	8.955e+03	3.929e+00	1.116e+04	1.821e+00
3	11	1.3672e+14	1.082e+01	1.207e+04	8.282e+03	2.114e-01	1.207e+04	2.933e+00
4	12	7.9804e+13	6.470e+00	1.218e+04	8.209e+03	3.230e+00	1.218e+04	2.873e+00
4	14	4.1157e+13	7.390e+00	1.308e+04	7.644e+03	4.124e+00	1.308e+04	1.330e+00
5	12	3.4082e+13	6.564e+00	1.119e+04	8.933e+03	3.098e+00	1.119e+04	1.171e+00
5	13	1.7749e+14	7.265e+00	1.198e+04	8.349e+03	3.779e+00	1.197e+04	5.655e+00
5	14	7.1297e+13	7.484e+00	1.209e+04	8.269e+03	3.991e+00	1.209e+04	2.213e+00
5	15	3.6137e+13	5.978e+00	1.267e+04	7.890e+03	3.081e+00	1.267e+04	1.428e+00
6	16	6.0041e+12	6.914e+00	2.502e+03	3.997e+04	-5.895e+00	2.508e+03	7.413e-02
6	17	1.3539e+13	8.413e+00	2.718e+03	3.680e+04	-4.761e+00	2.722e+03	1.470e-01
6	20	3.6844e+13	9.480e+00	3.054e+03	3.275e+04	-7.458e+00	3.061e+03	3.902e-01
7	19	9.8413e+13	8.612e+00	2.851e+03	3.508e+04	-7.740e+00	2.858e+03	1.086e+00
7	20	1.9723e+11	1.035e+01	2.203e+03	4.539e+04	-8.602e+00	2.212e+03	1.464e-03
8	18	8.6643e+13	1.195e+01	1.794e+03	5.575e+04	-1.014e+01	1.804e+03	4.672e-01
8	19	4.3033e+12	1.042e+01	2.567e+03	3.895e+04	-9.127e+00	2.576e+03	3.604e-02
8	20	2.3414e+12	1.216e+01	1.920e+03	5.209e+04	-9.989e+00	1.930e+03	1.316e-02
9	16	3.0010e+11	7.969e+00	8.153e+02	1.227e+05	-7.353e+00	8.226e+02	1.185e-03
9	17	1.9812e+11	9.468e+00	1.031e+03	9.703e+04	-6.219e+00	1.037e+03	8.173e-04
9	20	1.7992e+12	1.053e+01	1.367e+03	7.317e+04	-8.916e+00	1.376e+03	8.643e-03
10	17	7.1204e+11	1.073e+01	7.742e+02	1.292e+05	-6.897e+00	7.811e+02	1.988e-03
10	20	1.2786e+13	1.179e+01	1.110e+03	9.006e+04	-9.594e+00	1.120e+03	4.547e-02
11	17	-2.0562e+11	1.326e+01	-1.323e+02	-7.558e+05	-3.180e+00	-1.291e+02	8.197e-05

Figure 4

Calculated electron broadened line parameters of xenon at 10000°K and 7.65 ATM pressure, considering the j-l coupling-allowed transitions between the first twenty levels of the Table of Atom Energy Levels.[7] N, M are the numbers of the levels consecutively numbered from the ground state, F x N(N) is the product of absorption oscillator strength and the number of atoms per cm^3 in the lower state, DELTA NU is the width of line in cm^{-1}, NUO is the shifted position of the line in cm^{-1}, WAVELENGTH ANGSTROMS is the unshifted wavelength in Å, DELTA NU D is the shift of the line in cm^{-1}, and KAPPA PRIME (NUO) is the spectral absorptivity in cm^{-1} at NUO. **The wavelength listed as WAVELENGTH ANGSTROMS is the wavelength in a vacuum.**

including stimulated emission due to a broadened line for frequency in cm^{-1} is

$$k'_{\nu\,LM}(\text{in cm}^{-1}) = .8853 \times 10^{12} f_{LM} N_L \left(1-e^{-\frac{hc\nu}{kT}}\right) \frac{1}{\Delta\nu_w} \left[\frac{1}{1 + \left(\frac{\nu-\nu_{LM}+\Delta\nu_d}{\Delta\nu_w}\right)^2}\right]$$

The computer program for k'_ν considers all transition between the levels that contributed to the spectral absorptivity at ν; this may include contributions for the wings of many lines. The lines were assumed to have a Lorentz profile which is realistic for xenon at the conditions in the flash tube arc.

The program also prepares an input for a Cal Comp Plotter for the same conditions (with the particular scales to be chosen). Figure 5 shows the calculated spectral absorptivity due to the Stark-broadening lines for between 10000 cm^{-1}(1 μ) and 15000 cm^{-1}(.4μ). This calculated spectral absorptivity appears to agree quite well with that expected from observed spectra of xenon such as that of Figure 13 of Appendix C in Reference 3. The j-l coupling analysis does not include all of the observed lines. We are preparing an intermediate coupling calculation for xenon which will include the missing lines. The final form of these programs used in these studies will also be presented in the final report.

Work in progress includes combining the line spectral absorptivity with that of the continuum and the application to the arc model to give spectral radiance and the radiant emittance.

4. EXPERIMENTAL WORK.

The experimental work in the present portion of the investigation has been in three areas: determination of the radial temperature profile, studies of the partition of energy between that radiated external to the tube and that deposited in the walls, and more precise measurements of the plasma properties. All of these studies are currently in progress so they will only be briefly described.

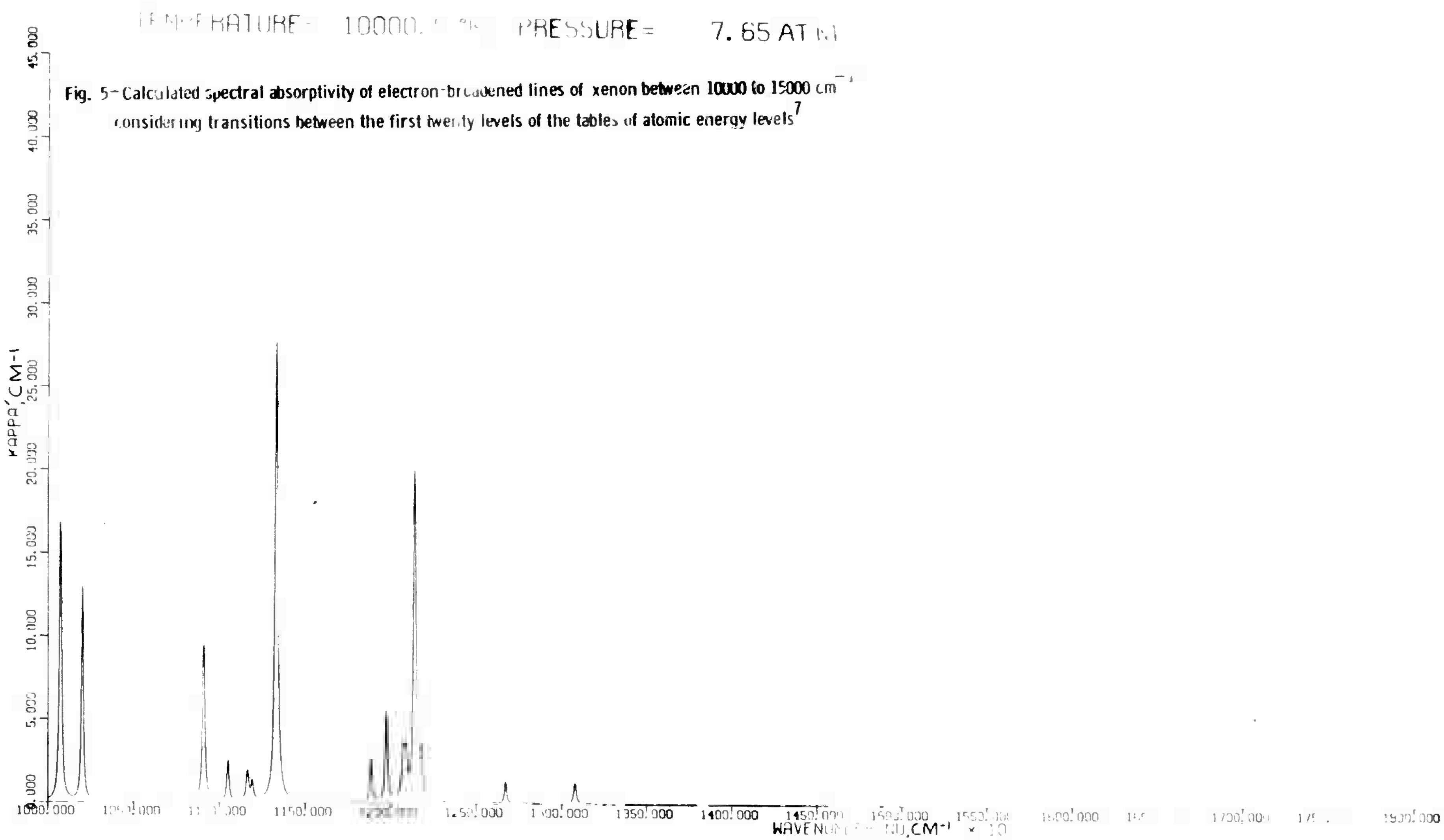

Fig. 5 – Calculated spectral absorptivity of electron-broadened lines of xenon between 10000 to 15000 cm^{-1} considering transitions between the first twenty levels of the tables of atomic energy levels[7]

Temperature Profiles

The determination of the temperature profiles is essential in evaluating the techniques for calculating energy transport within the arc, which in our models occurs either by radiation or thermal conduction. Our initial efforts described in the earlier reports[1,2,3] involved point by point radial scans with repeated firings of the flash tube. This technique was tedious and lacked the precision and accuracy desired, particularly in the portion of the arc near the wall.

Time resolved photographs made using the STL electronic framing camera indicated that some degree of kinking was present in the arc, particularly at the lower input powers. Some, but not all of the kinking, was attributable to the presence and the placement of the trigger wires wrapped about the tube. These photographs indicated that high speed radially traversing scans of the spectral radiance would provide more accurate and reproducible spectral radiance profiles.

To make high speed radial scans, an air-turbine-driven mirror from AVCO-MC300-2 streak camera has been incorporated into a high speed radial scanning apparatus. The mirror is capable of rotating at 1500 rps. The rotating mirror together with the triggering scheme used for high resolution rapid scan spectroscopy[14] will allow radial profiles to be determined at selected time intervals during the pulse.

Energy Partition

A series of experiments presently in progress are providing information on the partition of energy. We wish to distinguish between that radiated external to the arc and that carried to the walls by thermal conduction and radiative transport in the deep ultraviolet and far infrared where the plasma is optically thick. The quartz arc tube is opaque at wavelenths below about 1800A^{o} and beyond about 4 microns.

In the present experiments, a series of flash tubes of the same length and same initial xenon gas pressure, but varying diameter were fired over a wide range of energy inputs. The current and voltage across the tube were measured simultaneously with the spectral radiance at 8231.6Å. This wavelength is used to determine the temperature as the

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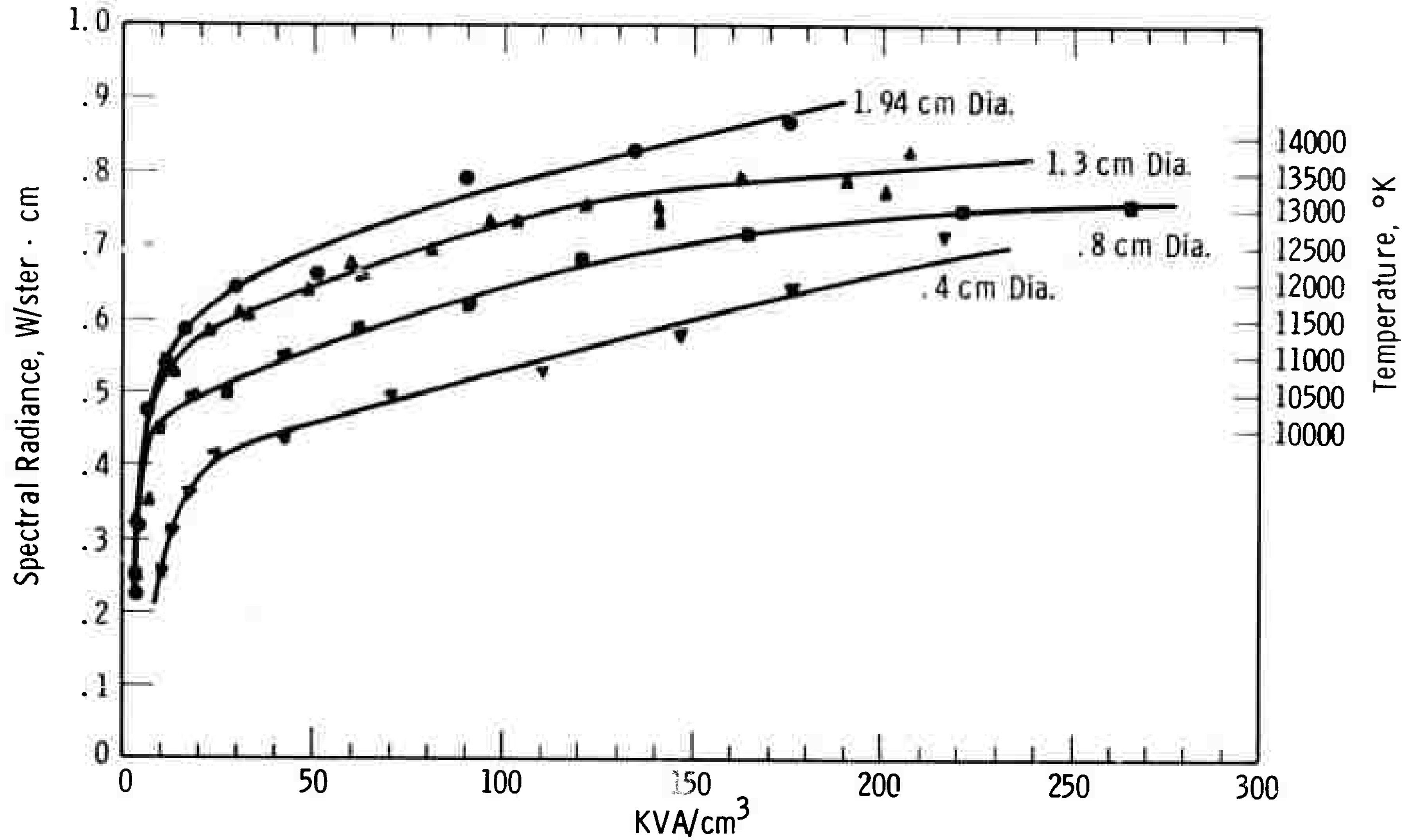

Fig. 6—Xenon-flash tubes. Experimental results. Spectral radiance at 8231.6 Å versus input power density. Initial pressure 150 Torr xenon.

xenon plasma is very thick at the wavelength under the conditions of operation. The initial gas pressure was 150 torr; the length of the arc was 30.5 cm. The flash tube diameters varied from .41 to 1.94 cm. We were planning to measure the instantaneous pressure using a Kistler 603 A transducer, but an accident to the unit necessitated our proceeding on while awaiting a replacement.

Figure 6 presents the experimental spectral radiance data obtained from this series of shots. The ordinate is the spectral radiance at 8231.6 Å and the equivalent black body temperature; the abscissa is the measured power density in KW/cm^3. The very early parts of all of the curves are probably not significant as the line used to measure temperatures may not be optically thick. Beyond this early stage, the slope of the temperature versus power density increases slightly with increasing tube diameter. For the same power density, the temperature increases markedly with increasing diameter, which also is increasing power per unit length in this plot. Earlier, in part 2 of this report, we described a simple model of the flash tube in which the thermal conduction and optically thick radiative portion of the energy varied in some fashion while the energy radiated external to the flash tube varied with the spectral radiance of the homogeneous temperature core of the arc. The data of Figure 6 agrees roughly with this model, but the detailed agreement requires a knowledge of the arc core diameter if not the temperature profile.

Theoretical calculations of the radiant emittance as a function of temperature using the values of the spectral absorptivity from our earlier work[3] indicated a variation of the radiant emittance with increasing tube diameter for the same temperature. For example, at 12000°K and 10.5 atmospheres pressure, the calculated radiant emittance was 7.6 $watts/cm^2$ for a .41 cm diameter arc, and 28.6 $watts/cm^2$ for a 1.94 cm diameter arc.

To obtain an estimate for the diameter of the arc core, the average electrical conductivity was calculated for the same data used to plot Figure 6. These average conductivities are shown in Figure 7. We assumed that the pressure in each of the tubes is the same for the same

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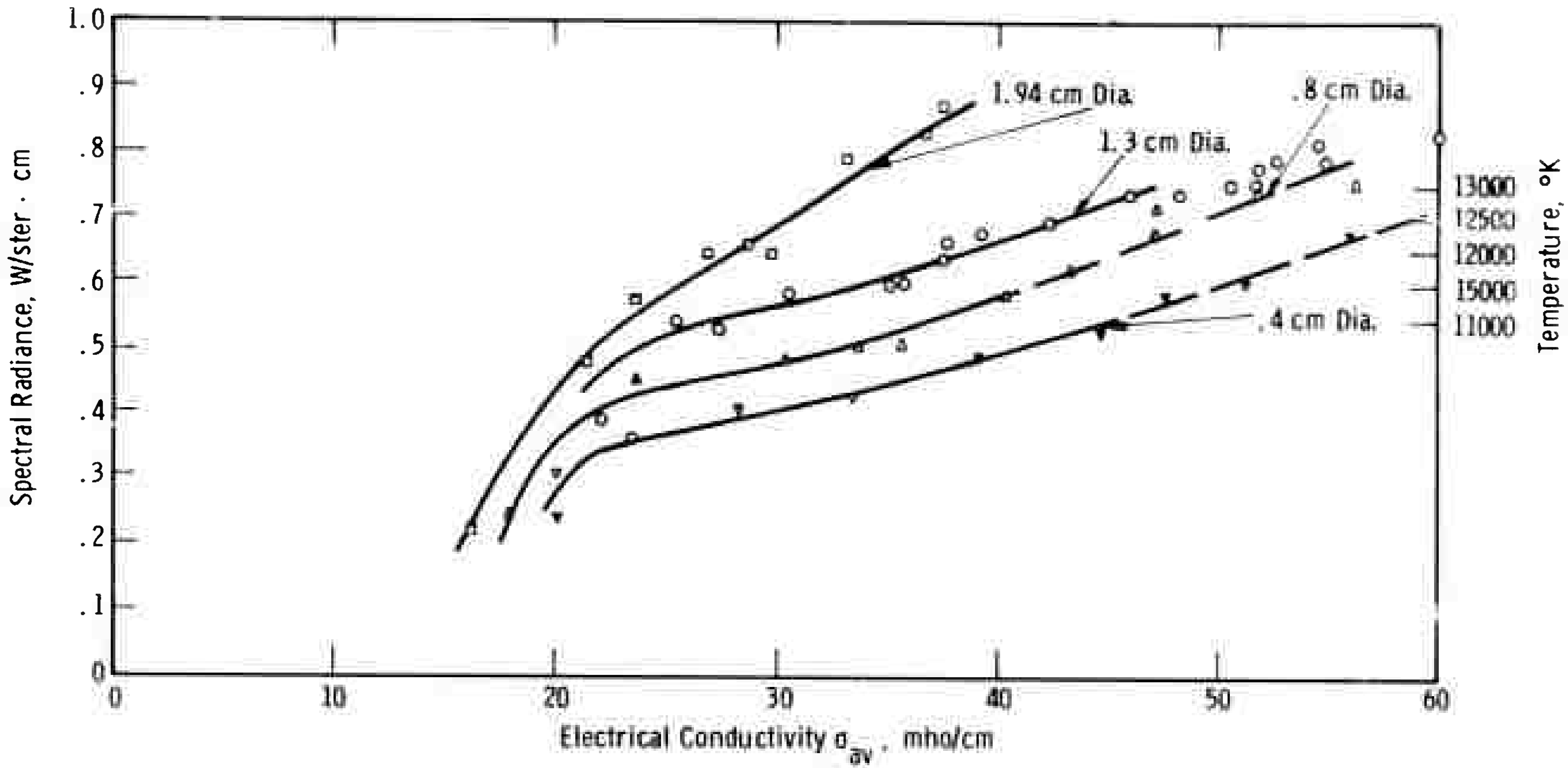

Fig. 7—The temperature dependence of the average electrical conductivity for tubes of varying diameter

respective temperatures; measurements of the instantaneous pressure would remove this possible source of error. A detailed more accurate calculation of radiant emittance will require consideration of the temperature profile to find the equilibrium pressure on the arc[1]. For the homogeneous temperature LTE arc the difference in the average electrical conductivities at the same temperature were taken to be due to variations in arc core diameter. For a rough estimate of the arc core diameter, we assumed that the arc completely filled the .41cm diameter tube and took that conductivity to be the true conductivity of the arc core.

The diameter of the arc core obtained in this fashion was determined to be .725 cm for the .80 cm tube; to range from 10.1 cm at 11000°K to 11.2 cm at 13000° for the 1.30 cm diameter tube, and to be 1.39 cm in the 1.94 cm diameter tube. Only in the 1.30 cm diameter tube was the arc core diameter found to vary with temperature. These diameters were then used to calculate the radiant emittance and radiated power per unit length of the arc core.

Figure 8 presents the thermal losses which were the conclusions from these measurements. The solid lines are the measured input power per unit length; the dotted lines are the calculated radiant emittances made using the continuum spectral absorptivities of Schlüter described in earlier reports[3]. The vertical arrows indicate the difference between the input power and calculated radiated power. To be noticed is the larger proportion of the power that is thermally conducted from the smaller tubes than from the larger tubes.

The variation of the thermal loss with temperature and temperature gradient agree at best only semi-quantitatively with the channel model. This data is only indicative as the spectral absorptivities used and the models themselves are not wholly accurate descriptions of the arc.

As we had mentioned earilier, measurements of the pressure simultaneously with the temperature and of the radial profile of the spectral radiance will aid in improving the model. To be answered by

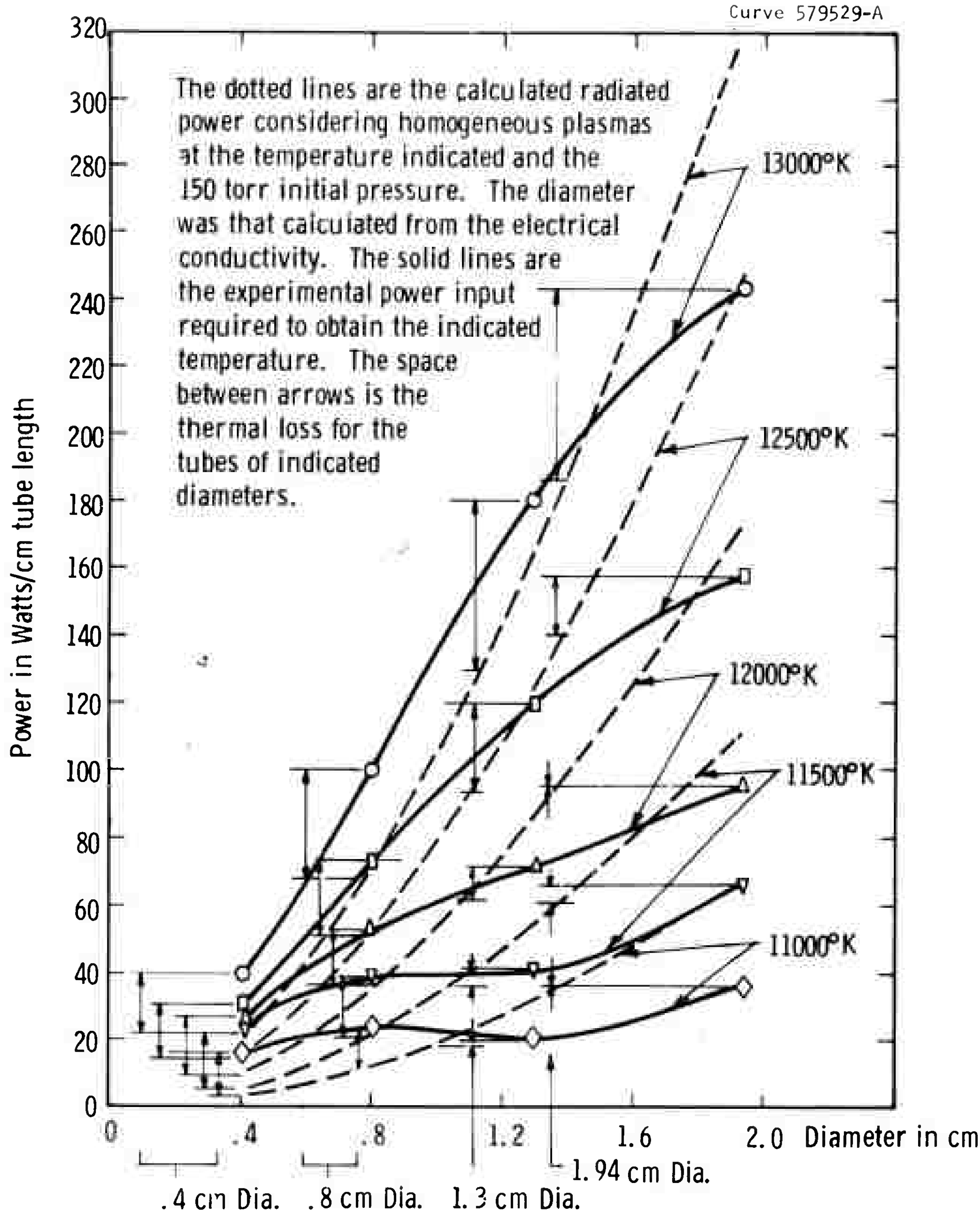

Fig. 8—The thermal loss in pulsed xenon discharges

the theoretical calculations of energy transport are the reasons for the wide variation of the boundary layer with tube diameter, but small variations with arc temperature.

Accurate Measurement of Physical Properties

More accurate measurements of the various physical parameters and properties that characterize the arc are also in progress. The aim in this portion of the work is to improve the accuracy and precision of the measurements. Also, more parameters of the arc are to be measured at the same arc conditions to define the arc more fully. To be included are measurements of the pressure simultaneously with the spectral radiance at a number of wavelengths in addition to 8231.6Å temperature reference. These measurements are being made with the arc viewed side on and end on. The end-on spectral radiance should be the same as the side-on at wavelengths where the arc is optically thick and vary in the ratio of the arc length to arc diameter at wavelengths for which the arc is optically thin (as the xenon arc is in the ultraviolet for the energy densities being studied).

Experimental techniques to be utilized for this include measurements of the physical observables such as current, voltage and spectral radiance using the Tektronix Type W preamplifier that allows a scan expansion of 10 and 100 to one if the noise level in the signal to be measured is low enough. This can be a problem for the low quantum efficiency S-1 photo surface photomultipliers when they are operated in the shot noise limited condition which is usually that existing in our experiments when we are using relatively high spectral resolutions. We are investigating an EG&G SGD-100 silicon photodiode (the guardring version of the EG&G SD-100) for the measurements. The photodetector has a high quantum efficiency, thereby reducing shot noise effects, and a low dark current noise. The low voltage level of the output requires more care in shielding from external noise than does the high gain (but shot noise limited) photomultipliers we have been using.

Measurements of the spectral radiance and of the line width and shapes are to be made using a new high resolution rapid scanning spectrometer to be described in a forthcoming publication.[14] Sample line profiles made using this instrument were in Figure 15, Appendix C of Reference 3. This instrument can measure the line profiles very well, but the accurate comparison with theory requires better electron density measurements. Measurements of the temperature profile and the pressure would determine the electron density; but more direct measurements would be preferable. We are investigating some laser interferometric techniques, but the opacity of the plasma in the flash tube in the visible and infrared may create problems for this type of measurement.

CONCLUSIONS AND SUMMARY

Theoretical calculations are being developed with the temperature and pressure dependence of the physical properties required to describe pulsed high energy arcs in xenon. The physical properties calculated thus far include the electrical conductivity, the thermal conductivity, and some portion of the spectral absorptivity due to free-free, bound-free, and bound-bound processes.

The pressure broadened lines are being incorporated into the model calculations. Further measurements are being made of a number of plasma parameters to test these calculations of the properties and to define further the characteristics of the arc.

A number of theoretical techniques are being investigated to solve the equations connecting the electrical energy input to the radiated and thermally conducted outputs from the flash tube. The major hurdle in the model studies is to obtain an accurate temperature profile without an unreasonable computer calculation effort.

To provide a simple model for the arc that may be applicable to move complex geometries, studies are being made to see how well arc models with homogeneous temperature cores and thermally conducting boundary layers agree with measurements. Comparison with experimental results indicate that the thickness of the boundary layer varies only slightly

with temperature but varies markedly with arc tube diameter. This type of model gives semiquantitative agreement with the experimental measurement.

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13. ABSTRACT

This report describes the recent work on the development of theoretical models for the pulsed xenon arcs used in high energy laser pumping. Included in this report are the results of theoretical calculations of line broadening and spectral absorptivities in xenon, and techniques for calculating the partition of energy in the flash tube between thermal and radiative conduction to the wall, and radiation external to the tube.

Experimental work in the report include measurements to describe the energy partition between conduction and radiation, and of the temperature profile of the arc. Progress toward more accurate measurements of the physical characteristics of the arc plasma are also described.

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